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HARVARD UNIVERSITY

6 PIGEON PROJECT,

Psychological Laboratories, Memorial Hall, Cambridge, Massachusetts

10 B.F./Skinner
C.B./Ferster

9 FINAL REPORT.

Period covered: 15 June 1949 - 15 June 1952,

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Introduction. Work done under this contract may conveniently be divided into three parts.

I. From time to time we have explored certain problems at the request of the Director of a classified project in another Naval Research unit. Reports have been made directly in consultation with this project. Work was discontinued in each case when the practical application was no longer important.

II. Because of the rapid progress made in the course of this research, many technical improvements and developments have become necessary, some of which should be regarded as important results. These are grouped together and discussed below under Section II.

III. Experimental results in the designated fields of research are described below in Section III. These may be listed under two principal headings.

1. We have explored ^{WERE EXPLORED} several problems in the chaining of responses, particularly in connection with the effect of a delay before reinforcement. Some of ~~our~~ results are in press in a paper by Dr. Ferster, "Sustained Behavior under Delayed Reinforcement" to be published in the Journal of Experimental Psychology.

2. ^{the} The major part of ~~our~~ work has been concerned with the effects of different schedules of reinforcement and different contingencies of reinforcement upon probability or frequency of response. ^{the} Some of these results have been reported in a lecture given by Dr. Skinner in Stockholm in July, 1951. This paper is to be reprinted in The American Psychologist. A much more exhaustive report will be published in book form by the Macmillan Company under the joint authorship of Drs. Skinner and Ferster, the book probably to be called "Schedules of Reward." It will include not only the major part of ~~our~~ ^{the} results under the present contract, but also some of the results to be obtained under ^{the} our new Contract N5ori-07656.

I. Points Checked for Practical Application

Visual acuity in close-up vision. The classified project with which we have been associated was at one time interested in the visual acuity of the pigeon in close-up vision. At the request of the Director, we studied this problem with two kinds of visual material. In the first experiment, photographic negatives were supplied by a Naval Research Office which were used to establish a discrimination in the pigeon between blocks of three bars presented vertically or horizontally, the blocks being square and with variable dimensions with outside dimensions proportional to the thickness of line. With this material we establish that pigeons can easily form discriminations when the side of the enclosing square is no greater than $1/32$ of an inch where the visual material is approximately $1\ 1/4$ inches from the eye of the pigeon.

For greater reliability we turn to the use of Ronchi rulings. Again a discrimination was established between vertical and horizontal positions. We were able to demonstrate the ability of the pigeon to discriminate between these

positions with rulings at more than 100 per inch. At this point we encountered technical problems concerned with defractions and with a source of light which we were not equipped to solve and since the practical question had been answered to the satisfaction of the other project, this research was dropped.

Reaction time. Another practical problem was the minimal reaction time of the pigeon to visual stimulation with and without a ready signal. We found that it was possible to establish reaction-time behavior in the pigeon comparable with that of the human subject and the reaction times appeared to be in the same order of magnitude. This work was also abandoned because our results indicated a satisfactory condition with respect to the practical problems of the other project.

II. Technical Developments

Introduction. One of the results of our general research in this area was a demonstration that such a subject as a pigeon could respond at rates as high as 20,000 responses per hour over long periods of time. We found it possible to extend our experimental period to as much as twelve or fifteen hours a day. These results presented severe technical problems in instrumentation and not the least of contribution under this project has been the development of apparatus suitable for such research. Some of the more important developments are as follows:

Keys. The response we have studied is the behavior of the pigeon in pecking at a small circular key 1 inch in diameter presented behind an open window. The operation of this key presents several problems. Ordinarily the pigeon will develop only as much energy as is needed to move the key and usually reaches a marginal energy where failure of many types of keys raises a serious problem. We have developed several kinds of mechanical and electronic keys having high natural frequencies and great sensitivity. We have recently developed a key in which the contact system is closed to prevent fowling from the dust which is characteristically given off by the pigeon under experimental conditions. Several of our models have natural frequencies above any frequency within the capacity of the pigeon (15 responses per second) which will operate for several million operations without attention.

Relay equipment. A special problem in research of this sort is to establish different controlling systems with speed and flexibility. We have worked out a technique of mounting relays and other pieces of equipment on panels which can be quickly assembled with snap leads.

Recorders. We have characteristically used a cumulative recorder. Necessary features include (1) a high rate of responding, (2) continuous duty over periods of many days, and (3) successful operation without attention for many hundreds of millions of responses. A recorder of this sort must reset automatically when the pen has moved from one edge of a paper to the other and must report other operations in the form of small pips on the cumulative curve. We have developed three successive models of recorders, the last of which solved these problems reasonably well.

Equipment for concept formation. We have developed a device which will present visual material for experiments in concept formation using an automatic slide projector, each slide carrying not only the material but a coding of spots of light which program an experiment. This apparatus has not yet been extensively used because for strategic reasons we have been using the equipment for somewhat more basic problems.

Schedule programmer. Some of the more complicated schedules of reinforcement which we have studied have required improvements in our programmers. We have developed a programmer for variable-interval and variable-ratio reinforcement which uses a teletype transmitter in connection with a relay tree. This permits the easy handling and construction of various schedules of reinforcement on both an interval and ratio basis.

Magazines. With the refinements in our experimental data it has become important to present food as a reinforcement for control periods of time. Some types of magazines permit the bird to gather up extra grains after the period of reinforcement proper has come to an end. We have developed two types of magazines which present a hopper of grain to a pigeon for a controlled period of time, then remove the grain at the end of that time so that the pigeon stops eating immediately and returns to the behavior being studied.

III. Experimental Results

Introduction. Since the experiments to be described differ considerably from those encountered in general in the field of animal behavior, a few introductory comments may be in order. We are concerned here with the behavior of an individual organism. Rarely do we concern ourselves with averaged curves or data of any sort. We are also concerned with the continuous record of the performance of the organism in which the probability or frequency of response at any given moment may be determined. These periods of experimentation extend up to fifteen hours per day on a daily basis. The data with which we are primarily concerned is the momentary rate of responding or changes in that rate as a function of different variables. The cumulative records we obtain are read with respect to momentary slope, curvature, and the fine "grain" of the record as an indication of the degree of uniformity or regularity of the behavior. In general we have studied the "steady states" achieved under various schedules of reinforcement, as well as the stages leading up to these steady states and the extinction of the behavior at any such stage. In general we have studied small numbers of pigeons, one or two ordinarily being used to study the effect of a given set of conditions. However, since our experiments overlap and interlock considerably, we usually acquire in the end a relatively large number of cases to establish any given point. Data at the present time, however, consist mainly of illustrative records. These are not selected as the best records to be obtained under a given set of conditions, but are offered as representative and typical examples of performance where repeated experimentation has satisfied the experimenter of the reproducibility of the results in every detail.

Results: Chaining of Responses and Delayed Reinforcement

Techniques were developed so that problems in chaining of responses could be studied by reinforcing a single response with the appearance of a stimulus

which is the occasion upon which the same response then produces food. Through the use of this technique we found that the effect of a delay in reinforcement on the probability of a response depends upon the formation of another link in a chain of responses. Some incidental response occurring during the delay period is accidentally reinforced. Under certain schedules it acquires a high probability. In reality, then, an apparent delay in reinforcement is simply the reinforcement of a second response in a chain. The factors governing the effect of a particular delay and the effect of a change from one delay to another were the same as those determining the formation of a chain of responses.

Results: Schedules of Intermittent Reinforcement

The types of schedules we have studied may be summarized as follows:

The response to be reinforced can be determined by an external clock (interval reinforcement) or by the previous responding of the organism itself (ratio reinforcement). We have studied the following variations:

Fixed. Reinforcement may occur at the end of fixed intervals or after fixed ratios of unreinforced to reinforced responses.

Variable. Reinforcement may occur at the end of a variable interval or after a variable number of responses (or ratio) since the preceding reinforcement.

Two-Valued. A case of some theoretical interest is reinforcement after an interval which assumes either one of two values on an unpredictable schedule (two-valued interval) or after a number of responses of either one of two values on an unpredictable schedule (two-valued ratio).

Tandem. The mechanisms operating under intermittent reinforcement are somewhat clarified by certain tandem schedules.

1. The principal schedule is fixed interval, but at the end of each interval the schedule changes to a small ratio, e.g., at the end of ten minutes the organism must emit ten responses and will be reinforced on the last of these.

2. The principal schedule is fixed ratio, but at the end of each ratio the organism is reinforced after the lapse of a small interval of time, e.g., the pigeon responds a hundred times and is then reinforced for the first response after ten seconds have elapsed.

3. Other interesting tandem schedules are variable interval leading to a small ratio and variable ratio leading to a small interval.

Mixed. Some important implications of intermittent reinforcement follow from certain schedules in which the organism is reinforced on different schedules for substantial periods of time, e.g., on a fixed-interval schedule for one hour, then on a variable-interval schedule for one hour, and so on. This permits us to observe the transition from one schedule to another.

Interpolated. In a variation on a mixed schedule a short period of reinforcement on one schedule is interpolated into a background schedule--e.g., a

short run of fixed-ratio reinforcements is introduced into a background schedule of fixed interval.

Interlocking. A schedule of reinforcement which has many analogues in the field of social behavior is one in which the organism is reinforced on a combination of interval and ratio schedules. On one such interlocking schedule, for example, the organism must emit a relatively large number of responses if it is responding rapidly, but will be reinforced for a smaller number if it responds more slowly. In this system the reinforcing mechanism is affected by the performance of the organism in a unique way.

Adjusting. Another way in which the reinforcing system may be modified by the behavior of the organism is exemplified by a schedule which changes progressively in terms of the performance of the organism at earlier stages in the experiment. Where the interlocking schedule changes during a single interval between reinforcements, the adjusting schedule changes after a given interval with respect to the interval which is to follow. In an adjusting ratio schedule the number of responses which the organism must emit before being reinforced varies with the rate of responding during earlier stages of the experiment.

Multiple. Any of the above schedules may be combined and placed under stimulus control. For example, the key which the pigeon strikes may be colored in different ways. When one color prevails, the pigeon is reinforced on one schedule; when another color prevails, it is reinforced on another. This is a multiple tandem schedule. In a multiple concurrent schedule the bird has access to two or more keys. These are necessarily under stimulus control because of their position but the stimulus control is also heightened by adding different colors to the keys. One key is reinforced on one schedule; another key on another.

Additional Contingencies of Reinforcement

In addition to schedules as such, it is possible to reinforce an organism in terms of its rate at the moment of reinforcement. For example, the organism may be reinforced on any one of the above schedules, but only when its rate is momentarily above a given value or momentarily below a given value.

Added Stimulus Feedback

Under these various schedules and contingencies of reinforcement, the organism is reinforced in the presence of self-generated stimuli which are important in the final determination of its behavior. It is possible to test the importance of such stimuli by adding external stimuli correlated with reinforcement in the same ways. For this purpose we have used a small spot of light projected on the key which the pigeon strikes. The spot may be made to vary with lapsed time since the preceding reinforcement, with the number of responses made since the last reinforcement, or with the momentary rate of responding. The feedback associated with the number of responses made in a given period of time may be permitted to "fade" according to some temporal schedule. Any of these types of feedback may be added to any of the schedules or contingencies already listed.

Probes

All of the preceding schedules may be established in advance of a given experiment and the behavior of the pigeon may be studied either in successive stages or in a final "steady state." Some information about relevant variables may be obtained by introducing single events into such a program. For example, a single response may be reinforced at any point in a standard record to determine the effect of a single reinforcement as such. We have probed behavior with a "blackout." The lights in the apparatus are turned out so that the bird does not (typically) respond. During this period of "dead time" the stimuli automatically generated by behavior are presumably permitted to grow weak.

RESULTS

We have studied the behavior of small groups of animals under all of the schedules and contingencies listed above. In general the behavior of the pigeon appears to be under the control of the stimulating conditions which prevail at the moment of payoff. These are the actual effect upon the organism of any given schedule of reinforcement or of any special contingency or of supplementary stimulation provided as a feedback. It is anticipated that the present research together with further research which is continuing under another contract will provide a fairly simple picture of the relevant conditions. Such a formulation would permit us not only to represent the effect of all these schedules but to predict the effect of any new schedule in advance. At the present time our results consist of a very large number of records obtained under these schedules. These are quite consistent, orderly, and highly reproducible from one organism to another. Some typical results were described in the lecture already referred to and the following excerpt from that report will show the general nature of this work.

Let us begin with the case in which reinforcements are arranged by a clock. We may represent such a schedule by drawing vertical lines on our cumulative graph. In Fig. 1 the lines are 5 minutes apart. We reinforce a response as soon as the pen reaches the first line, regardless of how many responses have been made. We reinforce again when it reaches the second line and so on. In other words, we simply reinforce responses at intervals of approximately 5 minutes. Call this "fixed-interval reinforcement." The organism quickly adjusts with a fairly constant rate of responding, which produces a straight line with our method of recording. The rate -- the slope of the line -- is a function of several things. It varies with difficulty of execution: the more difficult the response, the lower the slope. It varies with degree of food deprivation: the hungrier the organism, the higher the slope. And so on. It will be seen, moreover, that such a record is not quite straight. After each reinforcement the pigeon pauses briefly -- in this case for 30 or 40 seconds. This is due to the fact that under a fixed-interval schedule no response is ever reinforced just after reinforcement. The organism is able to form a discrimination based upon the stimuli generated in the act of eating food. (The process of forming such a discrimination has been thoroughly investigated with stimuli which may be better controlled.) So long as this stimulation is

effective, the rate is low. Thereafter the organism responds at essentially a constant rate. It would appear that stimuli due to the mere passage of time are not significantly different to the organism during the remaining part of the interval. The organism cannot, so to speak, tell the difference between say, 3 and 4 minutes after reinforcement under these circumstances.

In this record the rate of responding assumes two values -- it is zero so long as stimulation from the preceding reinforcement is effective; otherwise it is fairly high and constant, so long as the several factors just mentioned are not changed. Now, the pigeon is presumably stimulated by its own behavior. It must possess, so to speak, a crude "speedometer" which tells it how fast it is responding. Under fixed-interval reinforcement there are usually only two readings -- "zero" and "fairly fast." The pigeon is practically always reinforced at the latter reading. It is practically never reinforced for the first response when the reading is zero. The pigeon therefore is able to, and does, form a discrimination. We may put this in the form of a rule: when responding rapidly, continue to do so because your chances are good; when not responding, there is little or no reason to begin. We can see this rule in action if we withhold all further reinforcement. This brings about the process called extinction, in which the rate passes from a high initial value to practically zero. But extinction after prolonged fixed-interval reinforcement is not a simple process. Fig. 2 is a typical example. The pigeon begins at a high rate. This is a speedometer reading at which reinforcement has frequently been received. The chances of reinforcement are good and responding continues for several minutes. About 1000 responses are emitted at this rate. Eventually some sort of exhaustion sets in and the rate falls off, rather quickly, but in an orderly fashion, eventually to zero. This is a reading of the speedometer at which reinforcements have never been received; consequently, the pigeon does not resume responding for a long time. When another response eventually occurs -- for reasons which we cannot specify -- it restores to some extent the condition under which reinforcement has been received. Another response soon occurs, and this improves still further the speedometer reading. A high rate is quickly reached. Since this is again the condition under which reinforcements have frequently been received, responding is maintained for some time. Another group of approximately 800 responses appears. The rate then falls smoothly again to zero. Curves of this sort are satisfactorily accounted for by assuming, first, that when the organism is responding rapidly, it creates an optimal stimulating condition and, secondly, that when it is not responding, the stimulating condition is minimal.

A pigeon will continue to respond indefinitely when reinforcements are spaced as much as 45 minutes apart, even though food is received too slowly to maintain body weight, so that extra feeding is necessary between experimental periods. The behavior after each reinforcement shows a much slower acceleration from a low to a high rate. In extinction, the effect of self-generated stimuli is seen. Fig. 3 is an example, broken into two segments to show details more clearly. The pigeon begins as usual at a low rate of responding at A. It has never been reinforced at the start of the experiment or immediately after another reinforcement. A higher rate

develops smoothly during the first 20 or 30 minutes. This part of the curve is a fair sample of the behavior after each reinforcement on a 45-minute schedule. Eventually a rate is reached at which reinforcements have been most often received. (This is by no means the highest rate of which the pigeon is capable.) Because this is an optimal condition, the rate prevails for some time. When the pigeon pauses for a few moments, however (at B) it creates a condition which is not optimal for reinforcement. Responding is therefore not resumed for some time. Eventually another slow acceleration leads to the same high rate. When this is again broken (at C), another period of slow responding intervenes, followed by another acceleration. Eventually the rate falls off in extinction. Although such a curve is complex, it is not disorderly. It is by no means random responding. Since no external condition changes during the experimental period, the change in rate must be due to conditions altered by the bird's own behavior. The curve can be explained in terms of the self-stimulating effect of responding at special rates.

We can test the importance of the passage of time in accounting for behavior of this sort by giving the pigeon an external "clock." One such "clock" consists of a spot of light projected upon the key which the pigeon pecks. The spot marks time by changing size. At first it is only $1/8$ th of an inch in length. It grows to $3/4$ th of an inch at a given rate. The response to the key is reinforced when the spot is largest. When the pigeon returns to the key after reinforcement, the spot has again become small. Here is an external stimulus, then, roughly proportional to the time which has passed since the last reinforcement. Can it be used by the pigeon as a discriminative stimulus?

To avoid a disturbing complication we must get the spot of light into the experiment before it functions as a clock. Suppose we begin by holding the spot still at its largest size, and build up the usual fixed-interval performance. In Fig. 4 the upper curve shows a standard sample. The spot was set at "large" and the record is typical of reinforcement at intervals of 10 minutes. We now -- for the first time -- change the size of the spot, letting it begin at "small" to grow progressively larger during the interval. The spots in the circles above the lower record in Fig. 3 give sample readings of the clock at various positions. We observe that the pigeon is sensitively controlled by the size. When the spot is small it is most unlike its accustomed size, and the rate is almost zero. As the spot grows, the similarity increases and the rate rises. As the spot reaches its final standard size, the rate has reached or exceeded the value at which responses have been reinforced. Such a curve is not the effect of the passage of time; it is a report of stimulus generalization from large spots to smaller ones.

Eventually, however, the correlation between the size of the spot and the passage of time is felt. The pigeon begins, so to speak, to "tell time." In Fig. 5 a series of records show the progress of a pigeon in learning to use the clock projected upon the key. In each sample, three intervals are shown. In Record 1 the curvature is already somewhat sharper than in the preceding figure. As the pigeon is repeatedly exposed to the changing spot and is reinforced only when the spot is large, these

gradients become sharper still. By the time Record 5 is reached, the pigeon is not responding for approximately the first 7 or 8 minutes out of each 10. By that time the spot has reached a size very close to optimal and responding then begins and soon reaches a very high rate.

Eventually the pigeon characteristically waits fully 8 out of the 10 minutes and responds at a rate of 4 or 5 responses per second during the remaining part of the interval. It has formed a very precise size-discrimination. This would be the result without an added clock if the pigeon had what we call a precise "sense of time." But it is obvious that the unamplified passage of time is very insignificant for the pigeon compared with a physical clock of this sort.

The extent of the control exercised by the size of the spot is beautifully illustrated if we withhold further reinforcement while allowing the clock to run, repeating cycle after cycle of the growth of the spot from small to large as in Fig. 6. The pigeon continues not to respond during all sizes of the spot except those close to the value which has previously obtained at reinforcement. As repeated responses go unreinforced, however, the amount of responding to the high value progressively decreases. The extent of the control exercised by the spot can be shown in many other ways. We discovered one of these by accident. Our experiments are fully automatic and our apparatus is used 24 hours of the day. When we reached the laboratory one morning, we found that a pigeon had not responded all night long. Investigation showed that through an oversight the clock had not been started. The spot had remained at its smallest size for 15 hours. During this time the pigeon had not made a single response to the key. Another pigeon tested with the clock stationary at "small" waited 5 hours before responding. It then responded once and was reinforced. What happened is shown in Fig. 7. The first single reinforcement raised the rate of responding from practically zero to a definite and fairly stable value shown at B. The clock remained "small," of course. After 10 minutes the pigeon was reinforced again, whereupon the rate rose practically to its normal value without benefit of clock (C). The record is a good example of the effectiveness of single reinforcements. Only two reinforcements were necessary to restore the normal rate, and each did about half the job.

At the other extreme, we can show enormous power of the clock stopped at its largest size. Fig. 8 is a typical case. The record begins with three intervals of reinforcement during which the clock was running as before. The clock then remained at "large." During the next 10 minutes the bird responded nearly 2000 times. It was then reinforced, the spot continuing at large. The rate eventually fell off and, though not shown in the figure, it eventually reached the normal value under 10-minute reinforcement without benefit of clock. When time has been, so to speak, externalized in this way, it may be manipulated. For example, our clock may be made to run fast or slow. In one experiment, various speeds of "time" were introduced at random in successive intervals. The clock might complete one cycle in, say, 3 minutes, at the end of which time a response would be reinforced, whereupon the next cycle might require 16 minutes, and so on. The extent of the control exercised over the bird's behavior is

seen in Fig. 9 where typical performances for a range of clock speeds between 1 cycle in 3 minutes and 1 cycle in 32 minutes are shown. The rate of responding is roughly the same for a given size of spot regardless of speed of change. The curve at 32 minutes is obviously not approximately 10 times as high as that in 3 minutes, however, as it should be if the control by the spot were strictly equivalent in both cases.

It is also possible to run externalized time backward. Our first experiment of this sort was again an accident. The bird was being studied with a 3-minute clock and was responding as shown at the left in Fig. 10. The next day, through an oversight, the clock was run backward. It began large and grew small. The first 3 segments of the second curve in Fig. 10 are essentially inversions of the segments of the other curve. Since the bird was now reinforced when the spot was small, however, a new pattern quickly arose. The curve becomes essentially linear and at a later stage, not shown in the graph, the usual performance with a clock develops. Whether the spot of light is to grow or shrink with time is, of course, arbitrary, and the bird will adjust to either case.

We may eliminate the effect of time by adopting a different schedule. Reinforcements are still controlled by a clock, but the intervals between them are varied, roughly at random, within certain limits and with a given mean. In such a case the bird cannot predict, so to speak, when the next reinforcement is to be received. This is called a variable-interval reinforcement. The effect is a uniform rate of responding with great stability, which may be maintained for many hours. Fig. 11 shows a record in which the actual intervals ranged between a few seconds and 6 minutes in length. The randomized reinforcements are marked by small cross-dashes. Delays following reinforcement are lacking. Although the rate slightly changes from time to time, there is no pause as long as 10 seconds. The record, which is typical, covers a period of more than 2 hours. The control exercised by a schedule of this sort may be very great. During a single experimental record of 15 hours a bird responded 30,000 times. During this period the bird received less than its daily ration of food. Toward the end of the record there was one pause approximately 1 minute long, but otherwise, the bird did not pause longer than 15 seconds at any time during the 15 hours.

We turn now to an entirely different type of schedule. The moment at which a response is to be reinforced may be determined by the behavior of the organism itself. For example, we may reinforce every fifth response, every fiftieth response, or every two hundredth response. We call this fixed-ratio reinforcement, meaning that the ratio of unreinforced to reinforced responses remains fixed. In industry, this is called a piece-work basis of pay; the worker is paid in terms of his productivity. The pigeon's behavior under such a schedule is not too difficult to interpret. Fig. 12 shows a short segment of a characteristic performance. A response is reinforced every time the pigeon completes a group of 200 responses. Where we represented a fixed-interval reinforcement by drawing vertical lines on our cumulative graph, here we represent fixed-ratio reinforcement with a series of horizontal lines. Whenever the curve reaches one of these lines the response is reinforced, no matter how much time has elapsed.

The result is typically a series of gradients. Immediately after reinforcement a low rate of responding prevails; just before reinforcement, a high rate. The transition from one to the other is characteristically slower than under fixed-interval reinforcement. This difference appears to be due to another source of stimulation available under fixed-ratio reinforcement. In addition to a clock and a speedometer, the pigeon presumably has a "counter" which tells it how many responses it has made since the previous reinforcement.

An increase in its counter reading may be immediately reinforcing to the pigeon. One way to test this is to add an external counter comparable to the external clock. The spot of light on the key is made to grow, not with the passage of time, but with the accumulation of responses. If the pigeon does not respond, the spot remains stationary. With each response it grows a small amount. The effect of this externalized counter is dramatic. In one experiment the pigeon was being reinforced approximately every 70 responses. It was proceeding at an overall speed of about 6,000 responses per hour. As soon as a spot of light was added to the key, in such a way that it grew from "small" to "large" as the effect of 70 responses, the rate went up almost immediately to 20,000 responses per hour as in Fig. 13. Performance under fixed-ratio reinforcement in the absence of an external counter is presumably of the same sort, except that the pigeon's own counter is much less effective than the spot of light. It is possible to carry a pigeon to a high ratio without introducing appreciable pauses after reinforcement, but this process is slow and must be carried out with great care as the pigeon is made sensitive to its own counter.

We can prove that the pigeon is, so to speak, counting its responses by setting up a two-valued schedule of reinforcement. We reinforce the 50th response after the preceding reinforcement or the 250th, and we arrange our program in such a way that there is no indication in advance which ratio is to prevail. In such a case, the pigeon develops a step-like curve appropriate to a ratio of 50 to 1. But it shows this, of course, even when the ratio is actually 250 to 1. In Fig. 14, for example, the segments at A, B and C show either two or three waves which are the gradients prevailing under a reinforcement of 50 to 1. That is to say, the pigeon begins as if the ratio were to be 50 to 1. But after 60 or 75 responses have been completed there is a marked decrease in rate which can only be explained by assuming that the bird, so to speak, knows the score. A short period of slow responding follows. This gives way to a second gradient, again roughly of the order prevailing under 50 to 1 reinforcement. This may even be followed by a third gradient before reinforcement is received at the 250th response. If, as at D, we simply withhold all reinforcements, an extinction curve emerges in the form of a series of waves, averaging approximately 50 responses each. This cannot be due to the mere passage of time, since time does not show a wave-like character. It cannot be due to a discrimination based upon the rate of responding because this should lead to long segments at a high rate, as in both fixed-interval and fixed-ratio reinforcement. We have, then, to take into account a third source of automatic stimulation at the moment of reinforcement provided by a "counter."

We can eliminate the "counter" by randomizing a schedule of many different ratios. Fig. 15, for example, gives a typical record obtained under what we may call "variable-ratio reinforcement." A response was reinforced on the average every 110 responses, but in actual practice the very next response or a response as many as 500 responses later might have been reinforced. The schedule produces a very high rate of responding, sustained for long periods of time, showing none of the oscillations in rate characteristic of fixed-ratio reinforcement. The rate shown here is approximately 12,000 responses per hour.

This variable-ratio schedule is familiar to everyone, because it is the fundamental feature of all gambling devices. The pigeon responsible for Fig. 15 is not far removed from the pathological gambler. Variable-ratio reinforcement engages and holds the behavior of the organism with particular power. The magnitude of its control is seen when we extinguish the response. Fig. 16 is an extinction curve obtained after the variable-ratio reinforcement shown in the preceding figure. The curve has been broken into consecutive segments in order to avoid undue reduction. The curve begins with a long run of approximately 7,500 responses during which there is no appreciable retardation. The remainder of the curve is also illuminating. After short periods of slow responding the pigeon returns again and again to the original rate, which as the prevailing condition at previous reinforcements, tends to perpetuate itself. But the effects of variable-interval and variable-ratio reinforcement are very different, because the two schedules lead to different relations between reinforcement and the fine "grain" of the record. When reinforcement is arranged by a clock, the clock runs whether or not the pigeon is responding. The probability of reinforcement therefore increases during any pause. A response following a pause is especially likely to be reinforced. Under variable-ratio reinforcement, however, a pause does not alter the chances of reinforcement. There is no special likelihood that the first response made after a pause will be reinforced. On the contrary it is likely that a response occurring during a short burst will be reinforced, especially because a short burst is likely to be executed in its entirety before the reinforcement achieved by any one of its members is actually received.

We confirm this explanation by deliberately controlling the "fine grain effect." We arrange that a response will be reinforced only if it has been immediately preceded by a given number of responses during a given period of time. By insisting upon rapid responding in this way the rate under variable-interval reinforcement can be made to reach or even exceed the rate observed under variable-ratio reinforcement. Contrary-wise, we can introduce into our apparatus a device which insures that no response will be reinforced if it has been preceded by another response during a given interval of time. We insist upon slow responding. The effect of this upon variable-interval responding is clear cut.

Here the steeper curve shows a typical performance under variable-interval reinforcement. The other curve shows the performance of the same pigeon when a device has been introduced which prevents the reinforcement

of a response if it has been preceded by another response within 6 seconds. The overall rate of responding is simply reduced. The final slope depends upon the specified pause which is to precede the reinforced response.

Comparable results have been obtained for the other conditions specified above. Since the significance of these results, however, can be seen only when a unitary formulation of all schedules is possible, a report of details at this stage would be relatively meaningless and of no particular value. As already noted, the undersigned have in progress a full length book-manuscript to be published by the Macmillan Company which will bring together all these details under a unified theory of the effect of intermittent reinforcement.

B. F. Skinner, Director

C. B. Ferster, Research Fellow

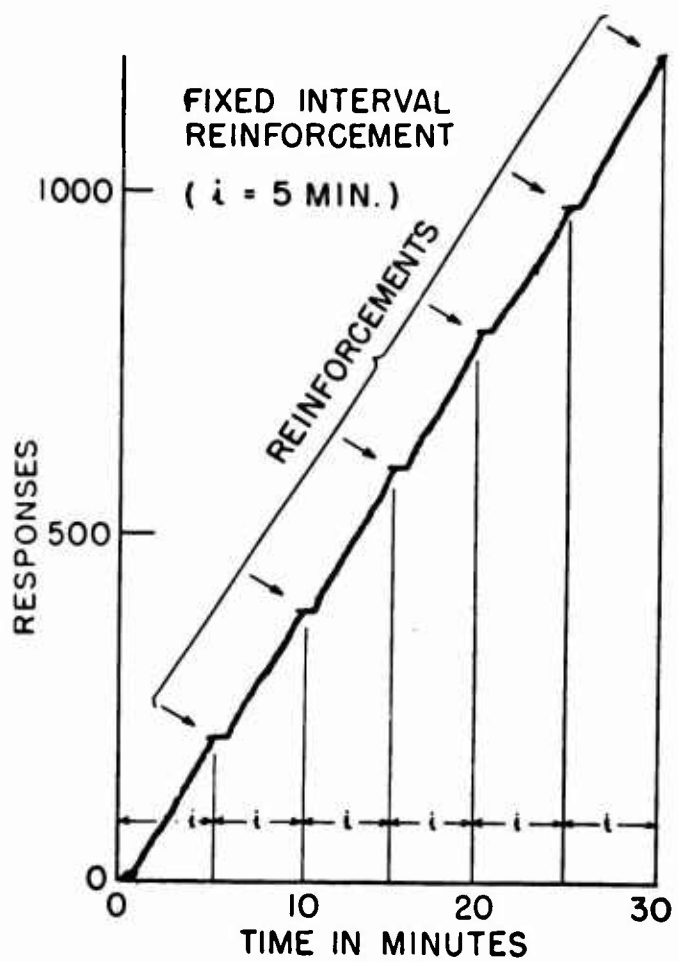


Fig. 1

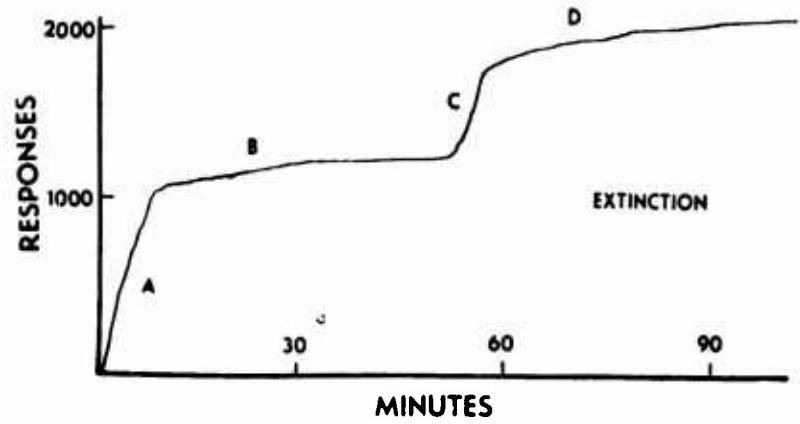


Fig. 2

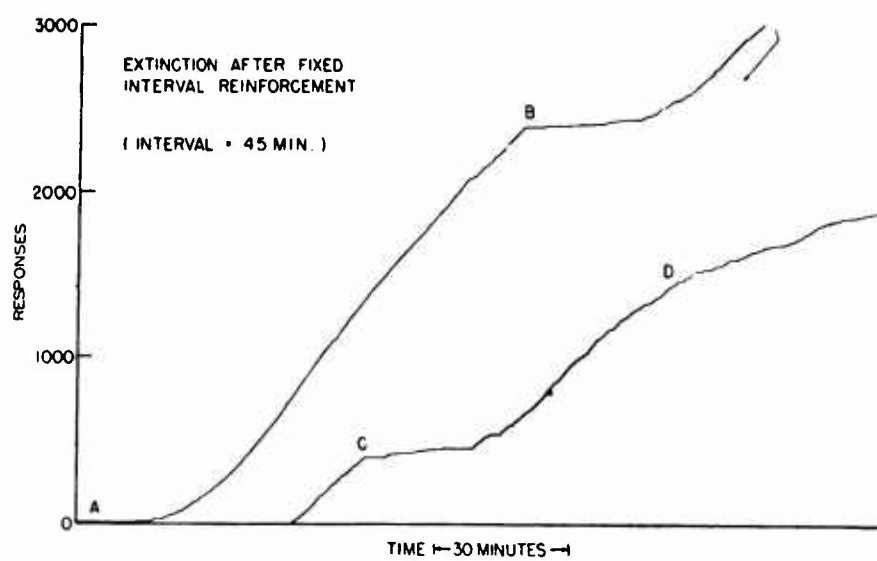


Fig. 3

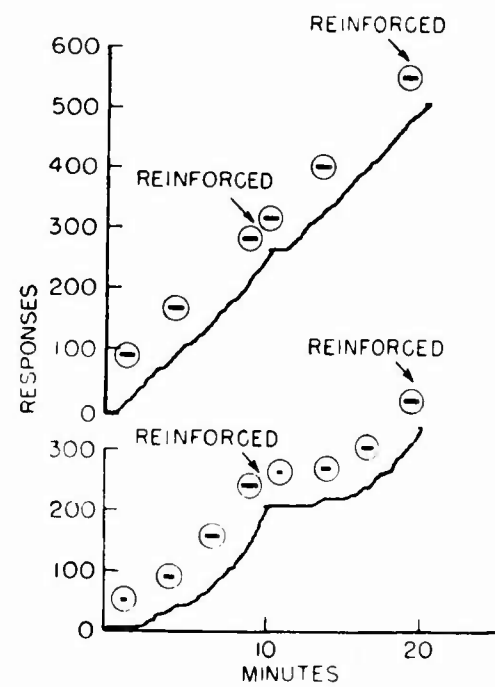


Fig. 4

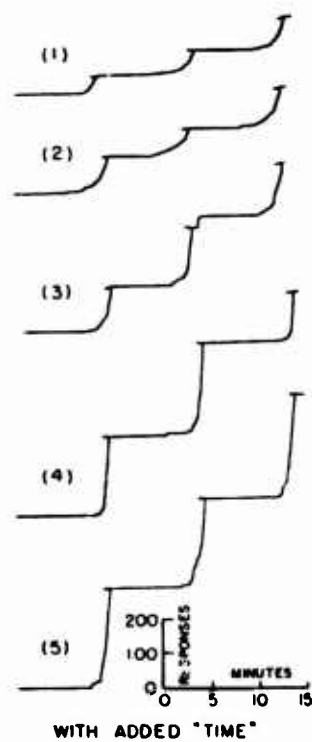


Fig. 5

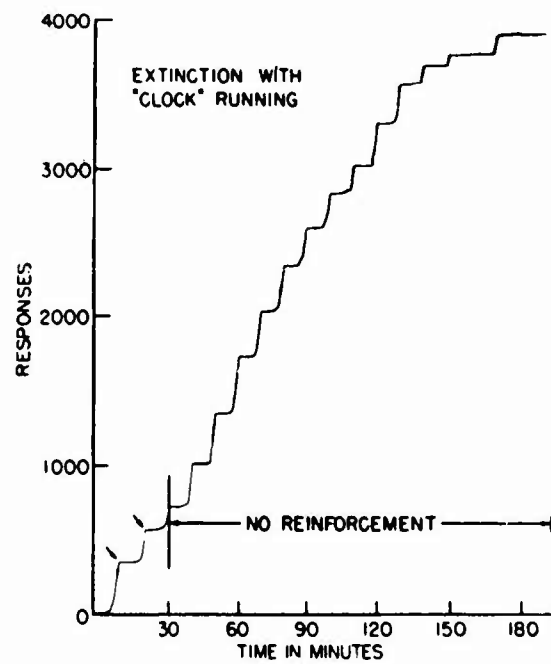


Fig. 6

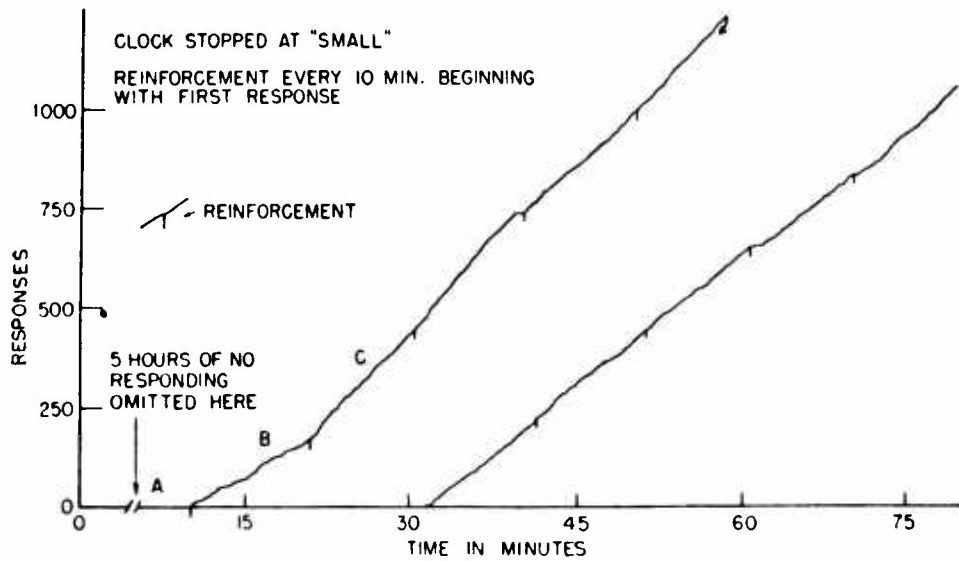


Fig. 7

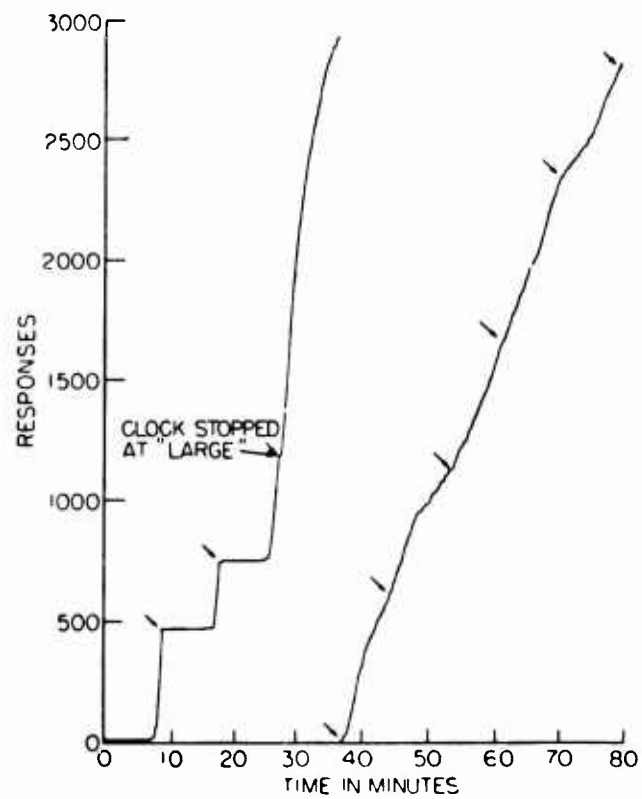


Fig. 8

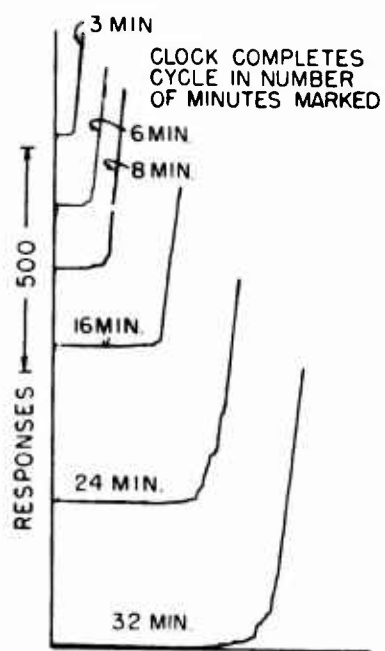


Fig. 9

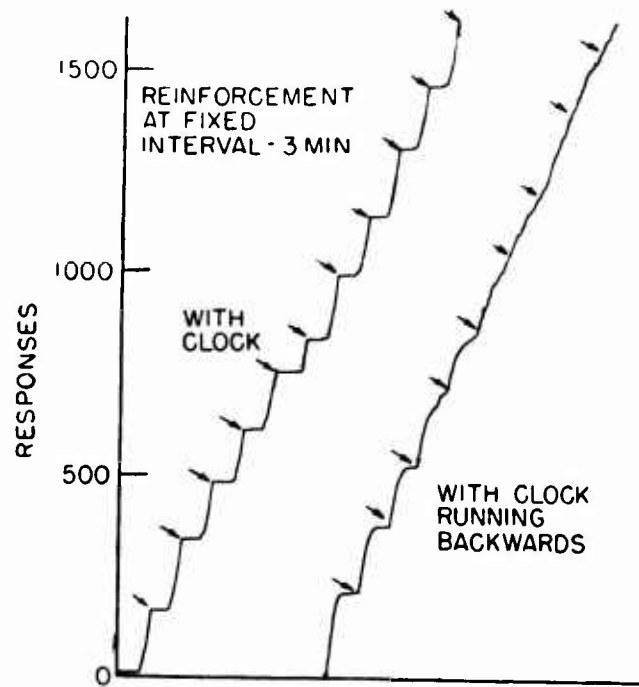


Fig. 10

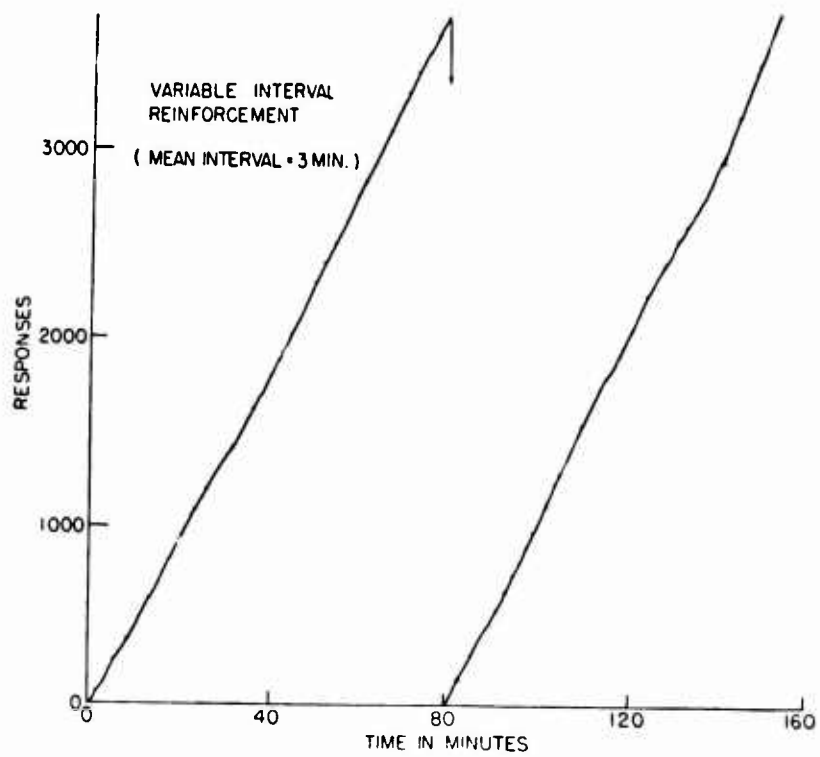


Fig. 11

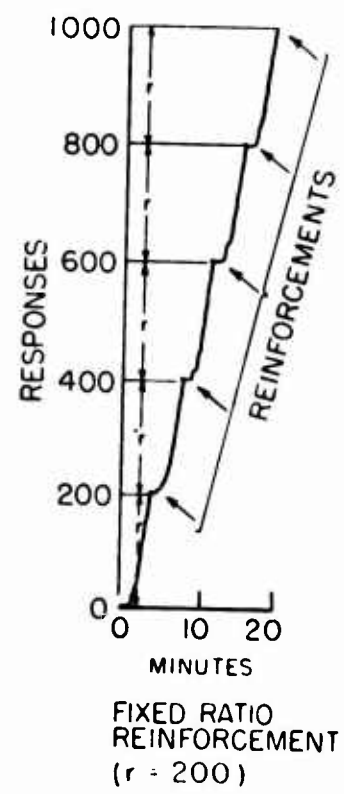


Fig. 12

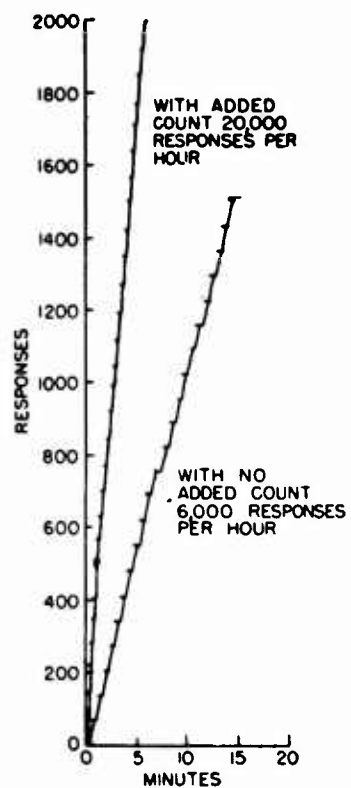


Fig. 13

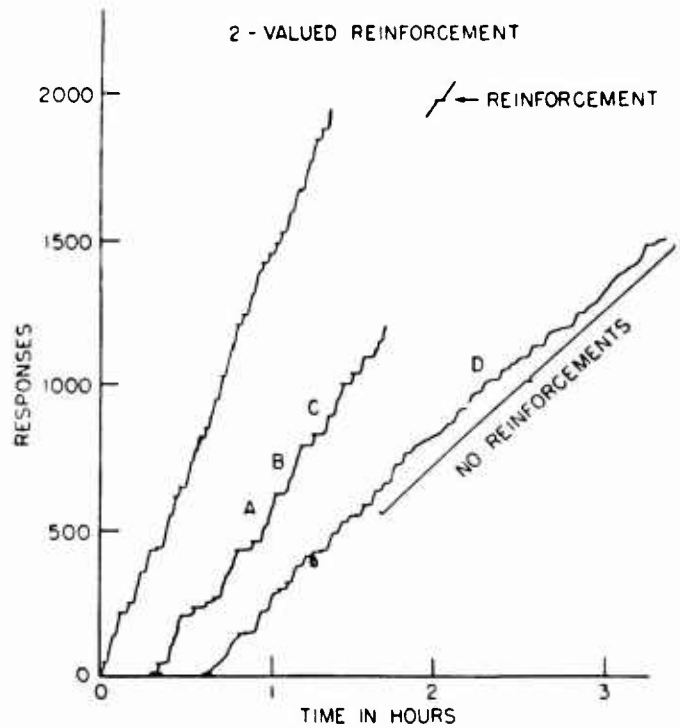


Fig. 14

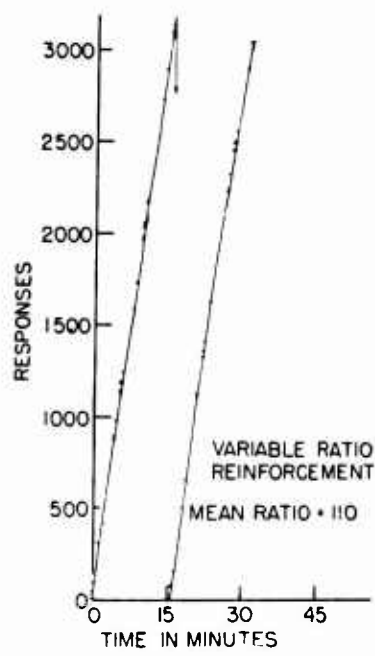


Fig. 15

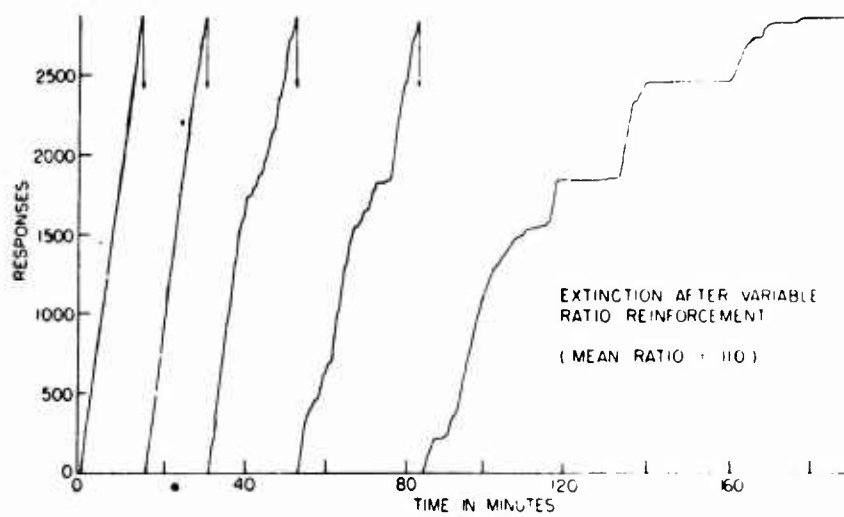


Fig. 16